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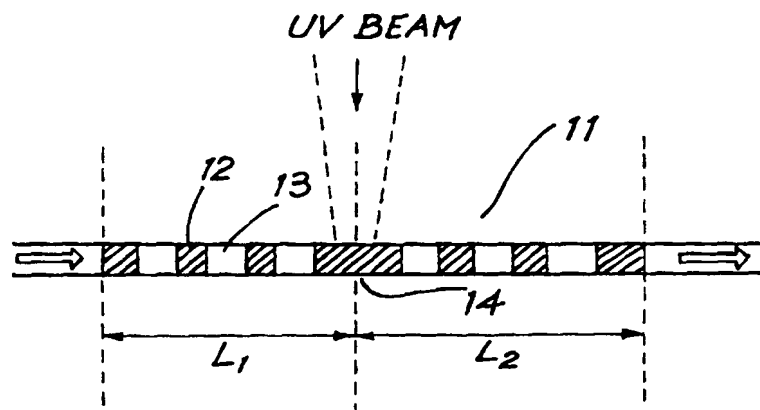
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| <p>(21) International Application Number: PCT/AU95/00069</p> <p>(22) International Filing Date: 14 February 1995 (14.02.95)</p> <p>(30) Priority Data:<br/>PM 3867 14 February 1994 (14.02.94) AU</p> <p>(71) Applicant (for all designated States except US): THE UNIVERSITY OF SYDNEY [AU/AU]; Parramatta Road, Sydney, NSW 2006 (AU).</p> <p>(72) Inventors; and<br/>(75) Inventors/Applicants (for US only): CANNING, John [AU/AU]; 35 Queen Street, Newtown, NSW 2042 (AU). SCEATS, Mark [AU/AU]; 19 Lenore Street, Five Dock, NSW 2046 (AU).</p> <p>(74) Agent: GRIFFITH HACK &amp; CO.; P.O. Box 4164, Sydney, NSW 2001 (AU).</p> | <p>(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).</p> <p><b>Published</b><br/>With international search report.</p> |   |

(54) Title: OPTICAL GRATING

(57) Abstract

An optical grating is formed by exposing linearly spaced regions of an optical fibre (10), typically a germanosilicate core fibre, to UV irradiation to produce spaced apart regions (12 and 13) of differing refractive index within the core (11) of the fibre. The grating characteristics are modified to create a relatively complex structure, for example a  $\sin(\pi x)$  phase-shifted distributed phase structure, by post-processing the grating. This is achieved by exposing at least one concomitant region (14) of the grating to localised UV irradiation.



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OPTICAL GRATINGTECHNICAL FIELD:

This invention relates to an optical grating, that is to a light transmitting device having periodic or aperiodic regions of differing refractive index in the direction of light propagation. The invention has particular application to optical fibres and is hereinafter described in the context of germanosilicate core fibres. However, it will be understood that the invention does have broader application, for example to planar waveguides and other light transmitting devices.

BACKGROUND ART:

The first optical grating or so-called Bragg grating was made in 1978 using the standing wave pattern originating from two counter-propagating beams in a Ge-doped core optical fibre. Since that time techniques have been developed to exploit the inherent photosensitivity of germanosilicate fibres, the photosensitivity being established by the bleaching of oxygen deficient centres by UV light to create the regions of differing refractive index. The refractive index change which is induced by the UV light arises from the creation of polarisable colour centres and structural rearrangement of the glass network.

Currently the most popular method of creating an optical grating involves so-called side-writing of a length of optical fibre using the holographic fringe pattern of two interfering UV beams. Side-writing of simple uniform periodic structures having a length in the order of about 1 cm with reflectivities approaching 100% and bandwidths greater than 1 nm has become an established practice, and attention is now shifting to the fabrication of complex grating structures for specific applications.

Side-writing of optical fibres by a recently developed point-by-point process has facilitated the fabrication of arbitrary phase gratings, and the employment of phase masks has been proposed for use in

the side-writing of non-uniform gratings such as phase shifted and chirped gratings.

DISCLOSURE OF THE INVENTION:

5 The present invention is directed to an alternative process for use in the creation of complex gratings and it stems from the discovery that grating characteristics may be modified to achieve a desired result by subjecting a grating structure to pre-processing or post-processing.

10 Thus, the present invention provides a method of forming an optical grating which comprises the steps of:

- (a) exposing linearly spaced regions of a glass light transmitting device to optical irradiation, the regions being spaced apart in the direction of intended light propagation through the device, and
- 15 (b) either prior to or following exposure of the linearly spaced regions, exposing at least one concomitant region of the device to optical irradiation.

20 The optical irradiation used for exposing both the linearly spaced regions and the concomitant region(s) has an intensity, dose level and wavelength appropriate to cause a localised increase in the refractive index of the device in the exposed regions.

25 The invention also provides an optical device which comprises or incorporates a grating produced by the above defined method. A complex grating may be so produced, for example a  $\pi$ -shifted distributed phase structure of the type required for a DFB laser.

30 The glass light transmitting device which is exposed to the optical irradiation preferably comprises an optical fibre and most preferably comprises a germanosilicate core optical fibre. However, any light transmitting device or any optical fibre having a core which exhibits photosensitivity may be employed. Thus, the present invention has application to the formation of  
35 a grating in any photosensitive light transmitting material within a waveguide. Germanium is recognised as being the leading photosensitive material and it is for this reason that the invention is most preferably

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directed to the formation of a grating within a  
germanosilicate core optical fibre. Co-doped optical  
fibres may also be employed, for example a germanium  
doped fibre core containing phosphorous and/or rare  
5 earths such as erbium and neodymium. The latter optical  
fibre has particular relevance in the development of  
lasing structures within a grating.

The optical grating is preferably formed by exposing  
the concomitant region(s) as a secondary step, that is  
10 following exposure of the linearly spaced regions. The  
secondary step thus may be referred to as a post-  
processing operation.

The linearly spaced regions may be uniformly spaced  
so as to form a periodic structure which effectively is  
15 made non-uniform or complex by irradiation of the  
concomitant region(s).

The intensity, dose level and wavelength of the  
optical irradiation will be dependent upon the structural  
changes to be made in the exposed regions and the  
20 characteristics of the material to be subjected to the  
radiation. The wavelength of the radiation will be  
selected according to the chemical composition and/or  
doping of the light transmitting device. In the case of  
a germanium doped device the wavelength of the radiation  
25 will be selected to be in the order of 240 nm, and the  
wavelength selected for other materials will be  
determined by the absorbcency of the material. The  
intensity and dose level of the radiation will be  
selected to create the required degree of structural  
30 change within a given material, with the upper limit  
being chosen normally to avoid fracturing the glass or,  
if appropriate, to control the degree of required  
fracturing.

In raising the refractive index generally within the  
35 localised region of the previously created uniform  
grating structure, a transmitted light signal will  
develop a retarded propagation. When the concomitant  
region of the device is located between the ends of the

previously created uniform grating structure, two gratings will effectively be produced which are out of phase with one another and which act as a wavelength selective Fabry-Perot resonator which allows light at resonance to penetrate the stop-band of the original (uniform) grating.

The method of the present invention, when used to introduce phase shifts which influence transmission and conversely reflection spectra, offers versatility and a potential for use in modifying spectral properties in more complex ways. The process in accordance with the present invention permits trimming of a grating structure and facilitates in-situ trimming of a grating. Trimming of the structure may be observed in-situ and any necessary adjustments may be made easily and quickly.

Applications of the invention include the production of very narrow band transmission and reflection filters. However, the method of the present invention has further applications, including the manufacture of "comb" gratings and "chirped phase shift" gratings. In the case of the comb gratings a series of phase shifts may be introduced into a grating given a sufficiently long bandwidth by adjusting different phase shifts at different locations along the grating. In the case of the proposed chirped phase shift gratings, these may be achieved by exposing a plurality of overlapping regions in a previously formed uniform grating, positioning the further region strategically along the grating.

The invention will be more fully understood from the following description of a preferred method of forming an optical grating within an optical fibre, the description being provided with reference to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS:

In the drawings:

Figure 1 shows a portion of the length of the core of an optical fibre and illustrates in an idealised way the post-processing of a uniform grating structure,

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Figure 2 shows an apparatus which is employed for side-writing a uniform grating structure into the core of the optical fibre,

5 Figure 3 shows an apparatus which is employed for post-processing the structure which is created in use of the apparatus of Figure 2,

Figure 4 shows graphs of normalised transmission spectra of an optical grating produced by the apparatus of Figures 2 and 3 - (A) prior to post-processing,  
10 (B) during post-processing and (C) following post-processing,

Figure 5 shows an alternative form of apparatus which is employed for side-writing a uniform grating structure into the core of the optical fibre,

15 Figure 6 shows an apparatus which is employed for post-processing the structure which is created in use of the apparatus of Figure 5, and

Figures 7A and 7B show graphs of transmission spectra of an optical grating produced by the apparatus of Figures 5 and 6 - (A) prior to post-processing, and  
20 (B) following post-processing.

MODE FOR CARRYING OUT THE INVENTION:

An optical fibre 10 that is to carry the grating structure comprises a 10  $\mu\text{m}$  diameter germanosilicate core and a 125  $\mu\text{m}$  diameter substantially pure silica cladding.  
25 Figure 1 shows a magnified view of a portion of the fibre core 11 in which the grating is formed.

A substantially uniform grating is formed initially within the core 11 by UV irradiation, using the  
30 holographic fringe pattern of two interfering beams, and the uniform grating is constituted by periodic, linearly spaced regions 12 and 13 of alternately high and low refractive index extending in the direction of light propagation. The grating as initially formed has a total  
35 length  $L_1 + L_2$  as required but typically in the order of 10 mm.

The grating constituted by the linearly spaced regions 12 and 13 is subjected to post-processing in one

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concomitant region 14, at the junction of the two grating portions indicated by the length  $L_1$  and  $L_2$ , by exposing the grating to localised UV irradiation as indicated in Figure 1. However, it will be understood that other post-processing operations may be performed to produce different structures, including for example structures in which two or more concomitant regions of the grating are exposed to further, localised irradiation and including structures in which a region 12 of "high" refractive index is irradiated to further increase the depth of refractive index modulation in that region. Also, it would be understood that similar structures may be achieved by subjecting the fibre 10 to pre-processing at region 14 by a localised UV beam and thereafter exposing the fibre to UV irradiation in a manner to form the linearly spaced regions 12 and 13 of alternately high and low refractive index. In either case (i.e., whether the localised irradiation is effected as a pre-processing or a post-processing operation), the localised irradiation is effected at least in part within the zone of the existing or intended linearly spaced regions 12 and 13. Thus, the localised irradiation is referred to herein as being for the purpose of exposing at least one concomitant region of the linearly spaced regions.

The uniform grating structure, which precedes the post-processing shown in Figure 1, is created using the apparatus of Figure 2. As illustrated, a 308 nm output (approximately 10 ns pulses) from an excimer laser 15 is used to pump a dye laser 16 producing 10 ns pulses at 480 nm. The output from the dye laser 16 is passed through a frequency doubling crystal 17 to produce pulses at 240 nm wavelength.

The output from the crystal 17 is reflected by a mirror 18 and passed through a cylindrical lens 19 such that its focal line is positioned at the output end of a prism interferometer 20. The prism interferometer produces a fringe pattern on this focal line and adjustment of the prism angle is effected to select the



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appropriate Bragg wavelength, this typically being in the order of 1550 nm.

5 The fibre 10 is stripped of its normal protective coating for a distance at least as long as the grating to be written, is placed along the focal line and is mounted in position using magnetic holders (not shown) so that it is maintained under a slight tension. The fibre 10 is located in front of the prism face without quite touching the face, and alignment with the focal line of the  
10 interference fringe is achieved by obtaining diffraction patterns at each end of the fringe when it strikes the core. The alignment procedure that is adopted is substantially the same as that employed in any interferometer which conventionally is used in the side-  
15 writing of optical fibre cores.

The fringe pattern then imprints a grating structure into the fibre core and this is monitored using a broadband source 21 at the Bragg wavelength selected for the grating on a spectrum analyser 22.

20 The procedure and apparatus described thus far for producing a uniform grating structure correspond in substance with the procedures and apparatus which conventionally are employed for side-writing prior art gratings. Alternative procedures that may be employed  
25 could involve the use of a narrow line width Excimer laser operating at 248 nm to write gratings directly, this providing a greater energy availability for use in writing Type II gratings. Also, any interference structure might be employed to produce the required  
30 interference pattern, for example a beam splitter used with two mirrors or, as hereinafter described, a phase mask.

In order to effect the post-processing a modified form of the above described laser system may be employed,  
35 as shown in Figure 3. However, in the post-processing operation the 240 nm output from the cylindrical lens 18 is focused directly onto the optical fibre 10 but with the focal line of the cylindrical lens located at 90°

relative to the fibre axis.

The post-processing is effected using the apparatus of Figure 3 whilst monitoring the appearance and movement of the phase shift dip on the spectrum analyser 21, again using the broadband source 20. As stated previously, the post-processing may be effected in one region only, as indicated in Figure 1, or at various regions within the uniform grating structure in order to produce a series of phase shifts in propagated light.

The results of monitoring the transmission spectrum are shown in the graphs of Figure 4. During post-processing and after approximately  $2.5 \times 10^4$  shots the desired result was obtained. A transmission peak at 1548.7 nm appears in the centre of the reflection band corresponding to the formation of a Fabry-Perot-like resonator structure. After a further  $2 \times 10^4$  shots this peak has moved to the lower wavelength side at 1548.5 nm.

Reference is now made to Figures 5 and 6 of the drawings, which show alternative forms of apparatus that are employed for side-writing the uniform grating structure into the core of the optical fibre 10 and for post-processing the structure which is created in use of the apparatus of Figure 5.

As illustrated in Figure 5, a phase mask 23 is arranged to diffract UV light at 240 nm, mostly in the +1 and -1 orders of diffraction, and it comprises a silica mask having 1 mm long parallel grooves 24 which are spaced apart with a period of  $1.06 \mu\text{m}$ , assuming that the uniform grating is to have an axial period  $P$  of  $530 \mu\text{m}$  to produce a Bragg reflection peak centred on  $\lambda_B$  of  $1.535 \mu\text{m}$ . The grooves 24 within the phase mask 23 are etched to a depth of approximately  $240 \mu\text{m}$ , and the grooves extend in a direction perpendicular to their length over a distance exceeding the length of grating that is to be written using the phase mask.

As in the previously described embodiment of the invention, when forming the grating, the fibre 10 is first stripped of its protective coating for the required

distance, and the fibre is placed directly behind the phase mask 23 such that the axis of the fibre is perpendicular to the grooves 24 within the phase mask. The fibre 10 is laid in V grooves 25 and is held by magnets 26, so that it is maintained under slight tension.

A laser beam having wavelength  $240\text{ }\mu\text{m}$  is generated by a frequency doubled Coumarin dye laser 27 pumped at 308 nm from an XeCl Excimer laser 28. The laser beam is pulsed at 20 Hz with a pulse fluence of  $1\text{ mJ/cm}^2$  over 36,000 shots.

The laser beam is directed onto the optical fibre 10 by way of the phase mask 23, the beam being deflected by a mirror 29 and focused by way of a fused silica cylindrical lens 30 which is located with its axis perpendicular to the fibre axis and, although not so shown in the drawings, positioned so as to produce a line focus along the fibre core.

The mirror 29 and lens 30 are both mounted to a carriage 31 in such a way that they may be moved as a unit in a direction parallel to the fibre axis. Thus, the focused, deflected beam from the laser is translated along the fibre by movement of the carriage 31 and is aligned in a way such as always to be incident with the same power density on the core of the fibre.

When writing the grating the carriage 31 is moved in the direction of the arrow shown in Figure 5 at a substantially constant velocity to create a uniform grating, and the grating is written into the fibre core as a consequence of the interference pattern created by the UV beam as diffracted by the phase mask.

Writing the grating is monitored using a source 32 (comprising a Hewlett-Packard 8168A tunable singlemode laser with a resolution of 0.001 nm, centred on 1520 nm) and a spectrum analyser 33, and the transmission spectrum as shown in Figure 7A is obtained prior to post-processing the uniform grating.

Having produced the uniform grating structure, post-

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processing is effected using the apparatus of Figure 5 but modified as shown in Figure 6 so that the 240 nm output from the cylindrical lens 19 is focused directly onto the optical fibre 10, with the focal line of the cylindrical lens located at 90° relative to the fibre axis. The beam is focused onto the centre 14 of the grating, over a length of approximately 1 mm, as formed in the apparatus of Figure 5.

During continuing post-processing of the grating structure the transmission spectrum is monitored and a transmission spike may be observed to grow in the reflection bandwidth, to establish the transmission spectrum of Figure 7B.

Variations and modifications may be made in respect of the procedure and apparatus described above whilst falling within the scope of the following claims.

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THE CLAIMS:

1. A method of forming an optical grating which comprises the steps of:

5 (a) exposing linearly spaced regions of a glass light transmitting device to optical irradiation, the regions being spaced apart in the direction of intended light propagation through the device, and

10 (b) either prior to or following exposure of the linearly spaced regions, exposing at least one concomitant region of the device to optical irradiation, the optical irradiation used for exposing both the linearly spaced regions and the concomitant region(s) having an intensity, dose level and wavelength appropriate to cause a localised increase in the  
15 refractive index of the device in the exposed regions.

2. The method as claimed in claim 1 wherein the light transmitting device is in the form of an optical fibre and the grating is formed within the fibre core.

3. The method as claimed in claim 1 or claim 2  
20 wherein the linearly spaced regions and the concomitant regions are exposed to UV irradiation.

4. The method as claimed in any one of claims 1 to 3 wherein exposure of the or each concomitant region to the irradiation is effected by way of a post-processing  
25 operation, following exposure of the linearly spaced regions and creation of regions of alternately high and low refractive index in the direction of propagation of light through the device.

5. The method as claimed in claim 4 wherein the or  
30 each concomitant region is exposed to the irradiation at a location intermediate the extremities of the linearly spaced regions.

6. The method as claimed in claim 5 wherein a  
35 single concomitant region is exposed to the irradiation at a localised region that bridges adjacent regions of relatively high refractive index.

7. The method as claimed in claim 5 or claim 6 wherein the or each concomitant region is exposed to

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irradiation at a level sufficient to establish a relatively narrow transmission region in the reflection bandwidth attributable to the grating.

8. The method as claimed in any one of claims 4 to 5 7 wherein the linearly spaced regions of alternately high and low refractive index are created by exposing the optical device to the holographic fringe pattern of two interfering beams.

9. The method as claimed in claim 8 wherein the 10 fringe pattern is established by use of a phase mask.

10. The method as claimed in claim 8 or claim 9 wherein the or each concomitant region is irradiated by focusing a beam directly onto the optical fibre.

11. A method of forming an optical grating 15 substantially as hereinbefore described with reference to Figures 2 and 3 or Figures 5 and 6 of the accompanying drawings.

12. An optical device incorporating a grating when 20 formed by the method as claimed in any one of the preceding claims.

13. An optical device comprising or incorporating an optical fibre which has a core formed with an optical grating, the grating having periodic or aperiodic linearly spaced regions of differing refractive index and 25 further having a concomitant region which is exposed to optical irradiation following formation of the regions of differing refractive index.

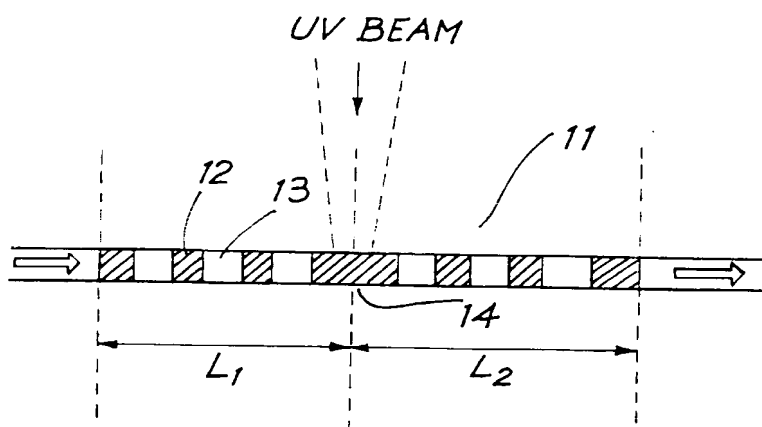


FIG. 1

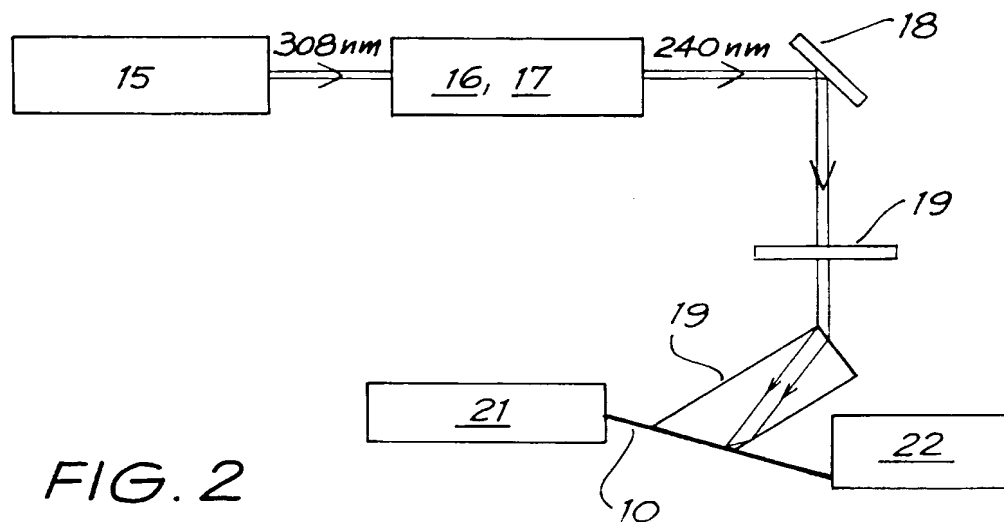


FIG. 2

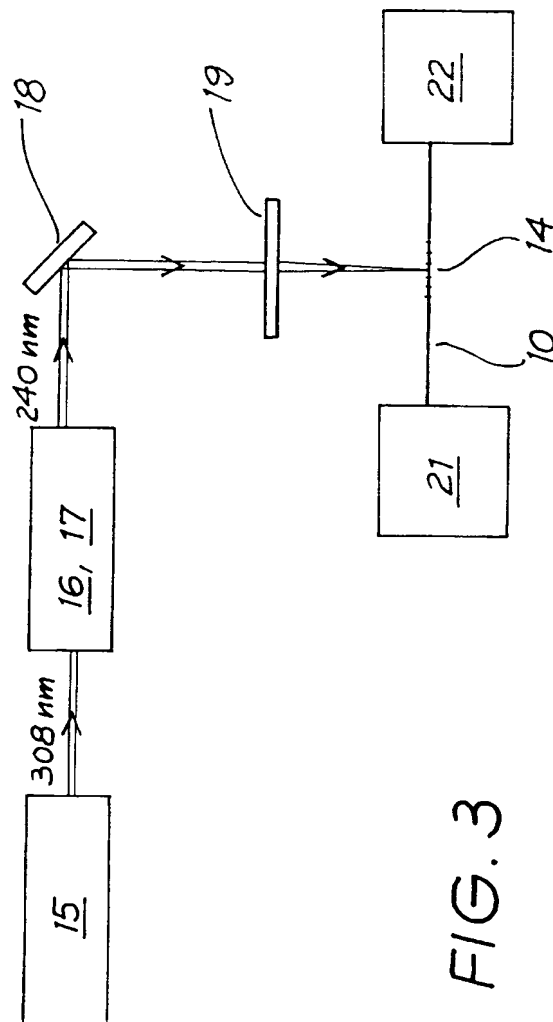
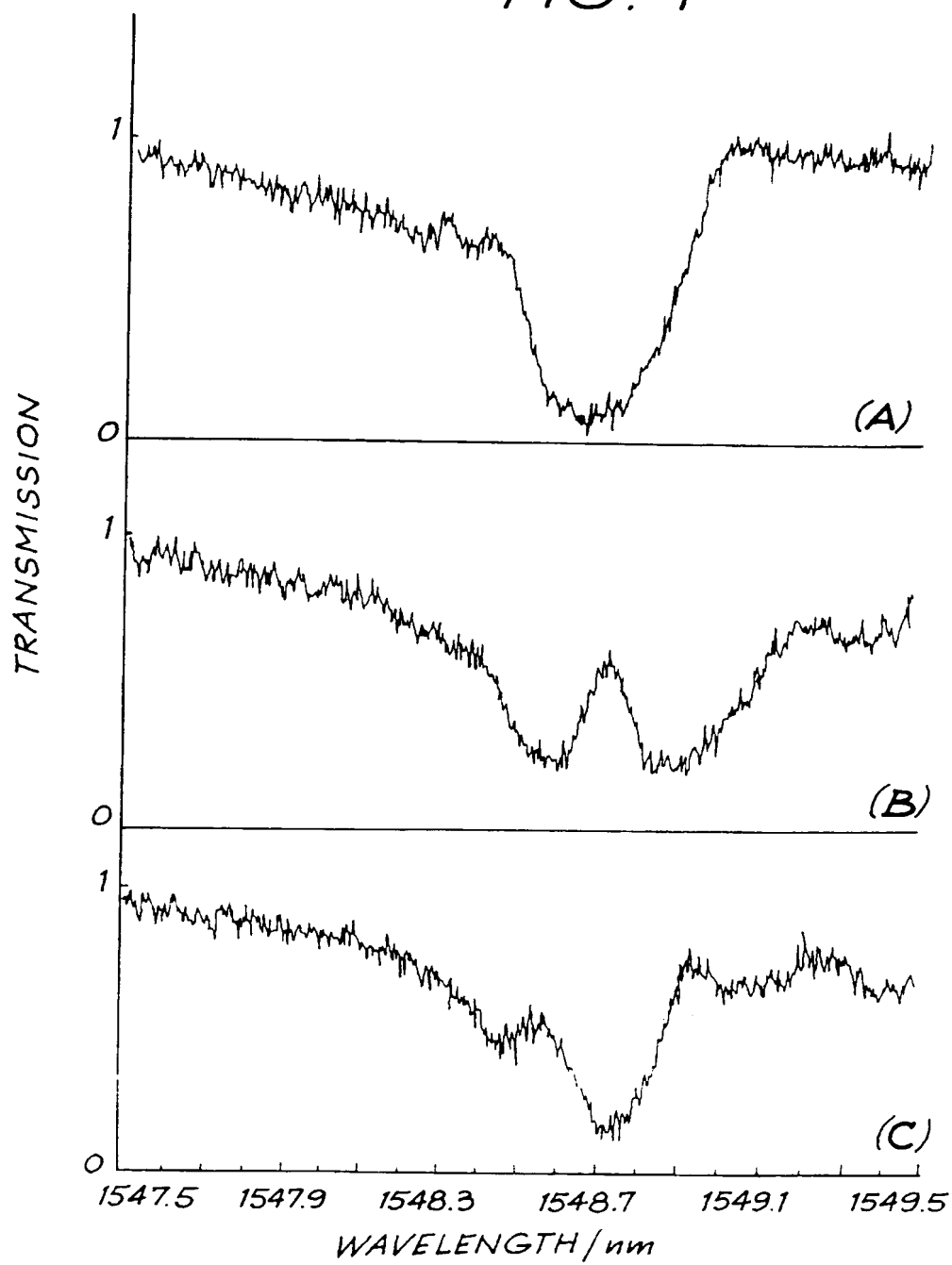
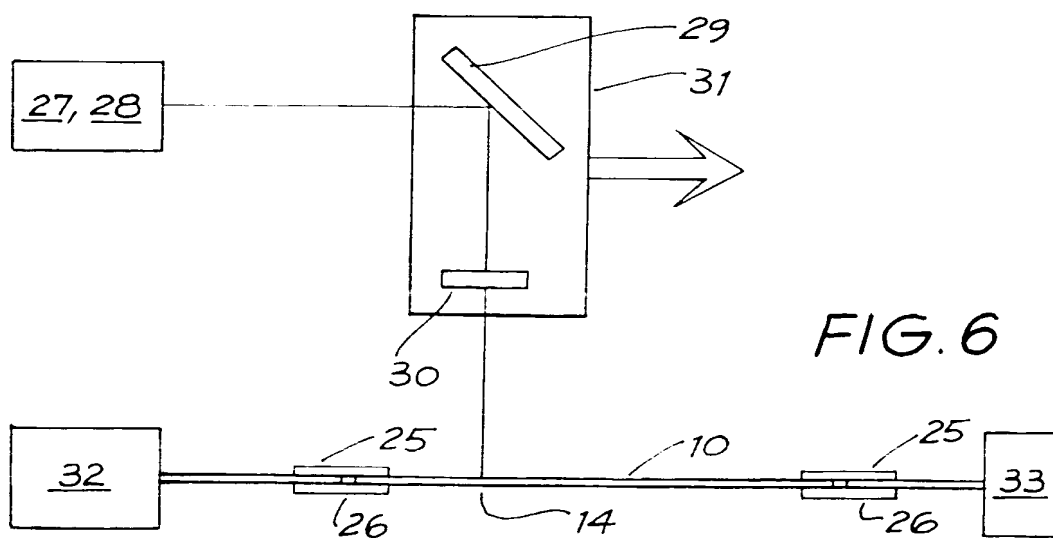
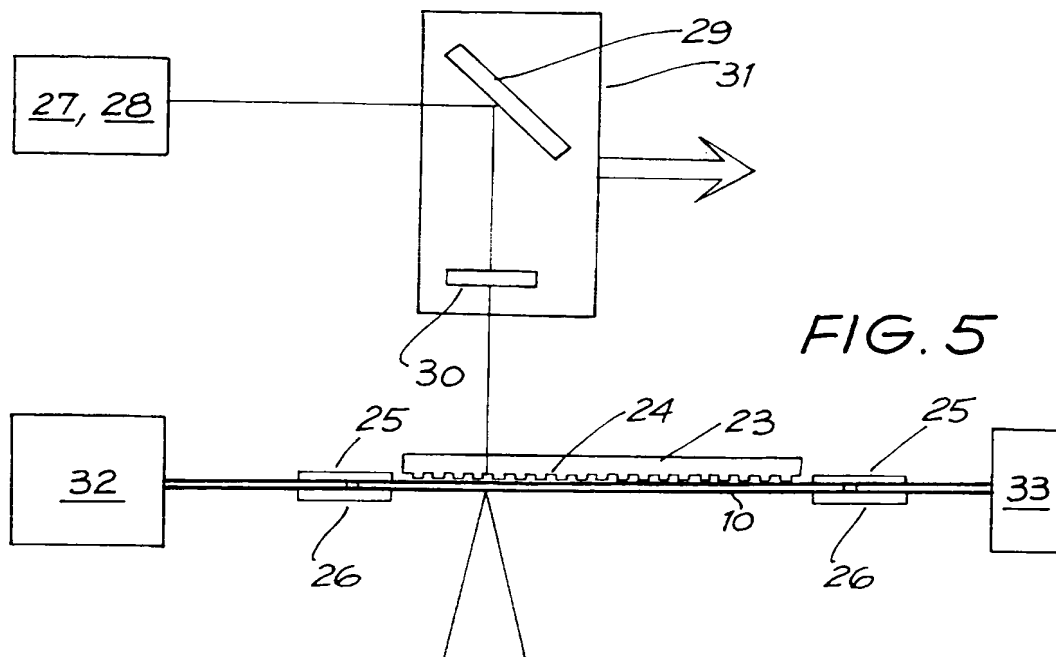


FIG. 3

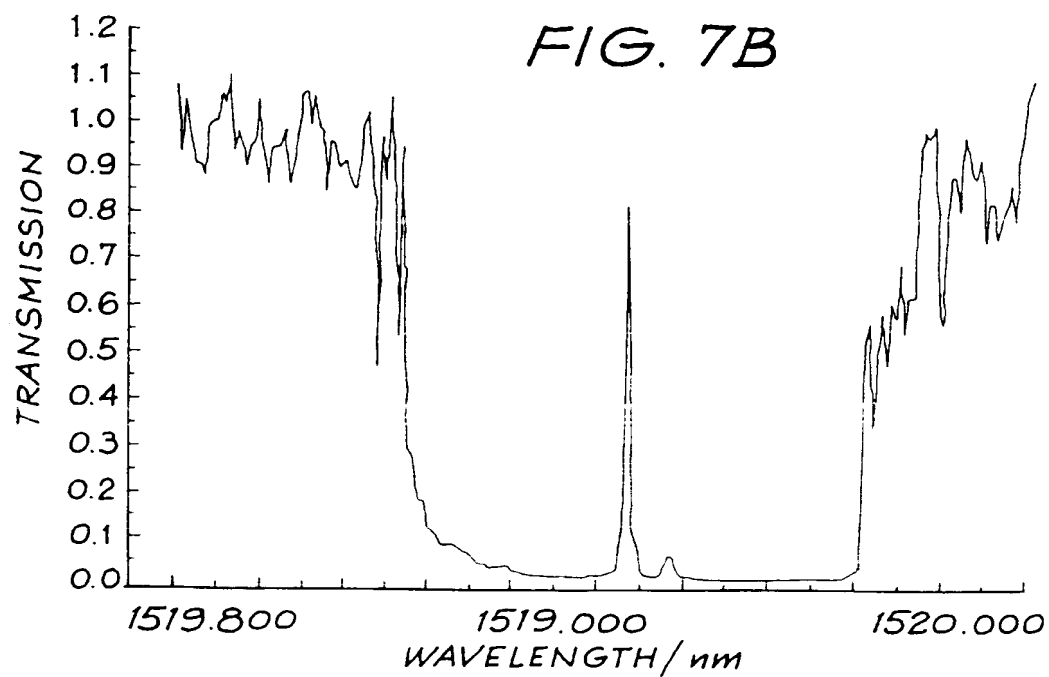
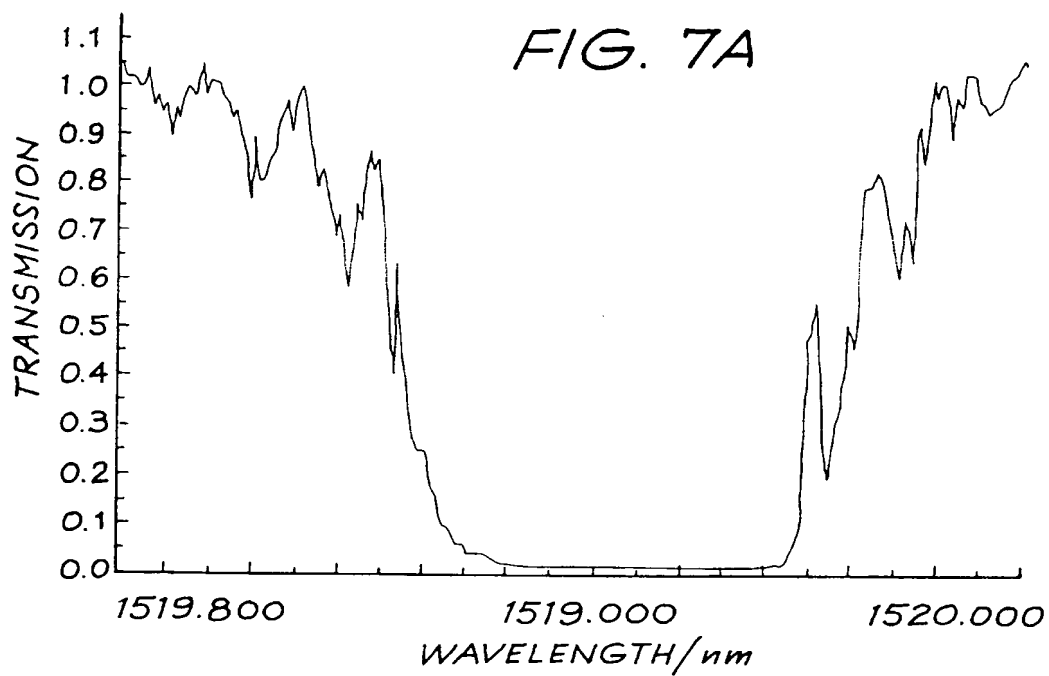


FIG. 4





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International application No.

PCT/AU 95/00069

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| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>Int. Cl. <sup>6</sup> G02B 6/10, 6/18, 27/44, 5/18<br><br>According to International Patent Classification (IPC) or to both national classification and IPC   |  |  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| <b>B. FIELDS SEARCHED</b><br><br>Minimum documentation searched (classification system followed by classification symbols)<br>IPC G02B 6/10, 6/18, 27/44, 5/18<br><br>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br>AU: IPC as above<br><br>Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)<br>Derwent, Japio: IPC as above with keywords:<br>grating, refractive index.  |  |  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>   |  |  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| Category*   | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to Claim No.  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| P,X   | US 5309260 A (MIZRAHI et al) 3 May 1994<br><br>Col 1, L22-31; Col 2 L17-26; Col 3, L1-3, 9-18; 26-36, 62-67; Col6, L46-50;<br>Col7 L26-28, 35-38<br><br>AU 26518/71 (443370) B (WESTERN ELECTRIC COMPANY, INC) 21 <sup>st</sup><br>September 1972. | 1-5, 12, 13  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| X   | P3, line 10-P4, line 4; P5, lines 11-13; P11, lines 5-9; page 15, line 11-P16, line<br>7; P27, line 20-P28, line 3; P31, line 15-P33, line 23; Figs 6,8  | 1-5, 8-10, 12, 13  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.   |  |  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| * Special categories of cited documents :<br><table border="0"> <tr> <td>"A"</td> <td>document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T"</td> <td>later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E"</td> <td>earlier document but published on or after the international filing date</td> <td>"X"</td> <td>document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L"</td> <td>document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y"</td> <td>document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O"</td> <td>document referring to an oral disclosure, use, exhibition or other means</td> <td>"&amp;"</td> <td>document member of the same patent family</td> </tr> <tr> <td>"P"</td> <td>document published prior to the international filing date but later than the priority date claimed</td> <td></td> <td></td> </tr> </table> |  |  | "A"  | document defining the general state of the art which is not considered to be of particular relevance | "T" | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention | "E" | earlier document but published on or after the international filing date | "X" | document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone | "L" | document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "Y" | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art | "O" | document referring to an oral disclosure, use, exhibition or other means | "&" | document member of the same patent family | "P" | document published prior to the international filing date but later than the priority date claimed |  |  |
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| "P"   | document published prior to the international filing date but later than the priority date claimed   |  |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| Date of the actual completion of the international search<br>23 May 1995  |  | Date of mailing of the international search report<br>1 JUNE 1995 (01.06.95) |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |
| Name and mailing address of the ISA/AU<br>AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION<br>PO BOX 200<br>WODEN ACT 2606<br>AUSTRALIA<br><br>Facsimile No. 06 2853929  |  | Authorized officer<br><br><b>M.E.DIXON</b><br><br>Telephone No. (06) 2832194 |  |  |     |   |     |  |     |  |     |   |     |  |     |  |     |   |     |  |  |  |

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU 95/00069

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| END OF ANNEX                                 |         |    |         |                      |         |    |         |